

“HE-Less” Detonator Modeling



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A combined modeling and experimental effort was undertaken to see if existing simulation tools at LLNL contain a combination of physics models suitable to study the initiation of high explosives (HE) by an electrical arc.

Project Goals

Our goals were to 1) determine if the shock initiation model implemented in a particular ALE hydrocode is capable of reproducing previously measured arc initiation data; and 2) if so, to map out the space for an arc-based detonator that would not require its own internal HE (an “HE-less” detonator). The experimental effort provides a map from fireset parameters to shock pressures, and the modeling effort gives a map from shock pressures to initiation.

Relevance to LLNL Mission

Arc initiation phenomena are directly relevant to LLNL stockpile safety studies and to improved initiation system plans.

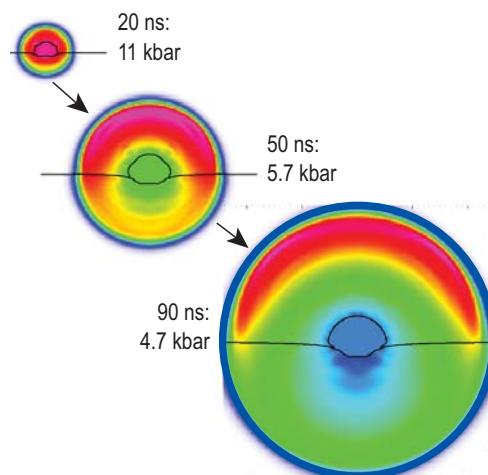


Figure 1. Air bridge model of arc-initiated PETN.

FY2007 Accomplishments and Results

In the modeling portion of the project, an existing 2-D ALE hydrocode model of pentaerythritol tetranitrate (PETN)-based exploding bridge wire (EBW) detonators was modified to simulate an arc-driven “air bridge” in place of the metal bridge wire. To avoid attempting a first-principles model of the arc itself, the electrical behavior of the air bridge was matched to experimental measurements. An extensive matrix of studies was performed in a parameter space containing the initial arc radius, the source capacitance, source inductance, and source voltage. Figure 1 shows a typical result of the simulated pressure field in PETN that was successfully ignited by the air bridge.

The intent was to see if the simulated “go vs. no-go” results resembled data taken from a set of measurements of detonator sensitivity to electrostatic discharge (ESD). In particular, we looked to reproducing the observed trend of lowered threshold with decreased circuit inductance, which we chose as our indicator that the shock-based initiation model was sufficient. Further simulations would then map out the arc-driven shock pressures useful in a detonator intentionally engineered to use arc initiation.

However, as shown in Fig. 2, while the simulations do show arc initiation of PETN, they do not reproduce the observed dependence of threshold energy on inductance. It has not yet been determined if this is due to the assumption that only shock pressure participates in the initiation mechanism, or to the lack of a significant energy transport mechanism in this particular mode of operation of the hydrocode, or to a purely numerical effect not discernible in simple baseline tests.

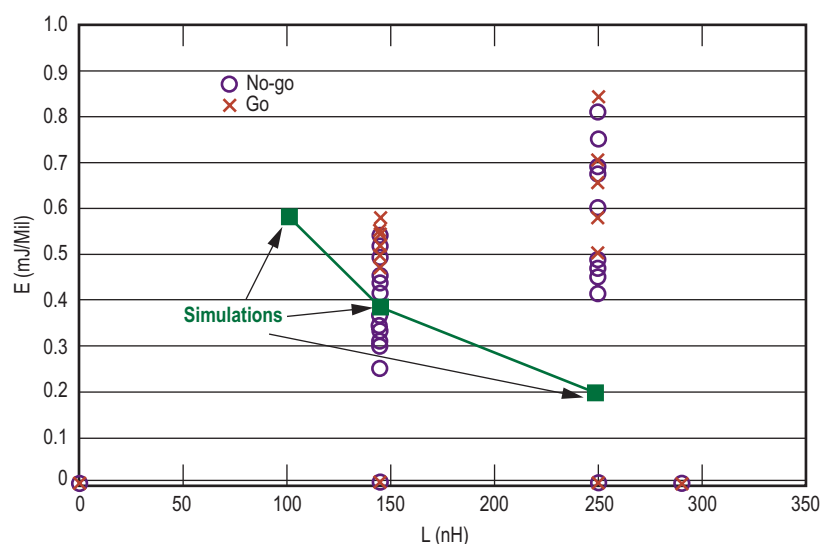


Figure 2. Simulated and measured energy thresholds. The agreement at 150 nH is forced by fixing the energy and finding the threshold in initial arc radius. The resulting radius (0.9 mil) is then used to find the energy thresholds at 100 and 250 nH.

In the complementary experiments, photonic Doppler velocimetry (PDV) was used to measure the velocity front of an arc in air, using fireset parameters scaled to match the detonator ESD safety study. The setup is shown in Fig. 3. The purpose was to determine if the shock pressure required to drive the expansion of the air was of the right order for shock initiation of HE; and, if so, to

build a map between electrical parameters and the pressures produced in the resulting arcs. This map could then be combined with the modeling study to find fireset parameters that would produce initiation in a variety of useful HES (since the model itself lacks a first-principles coupling between the fireset and the resulting arc). However, as shown by the typical results in Fig. 4,

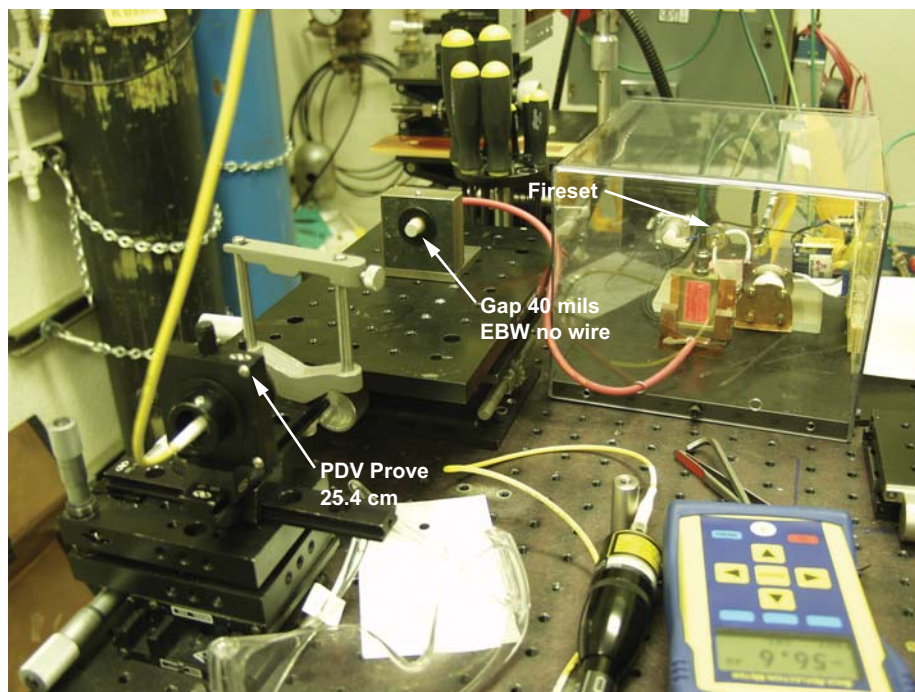


Figure 3. Experimental setup for PDV measurement of arc-driven air expansion speeds.

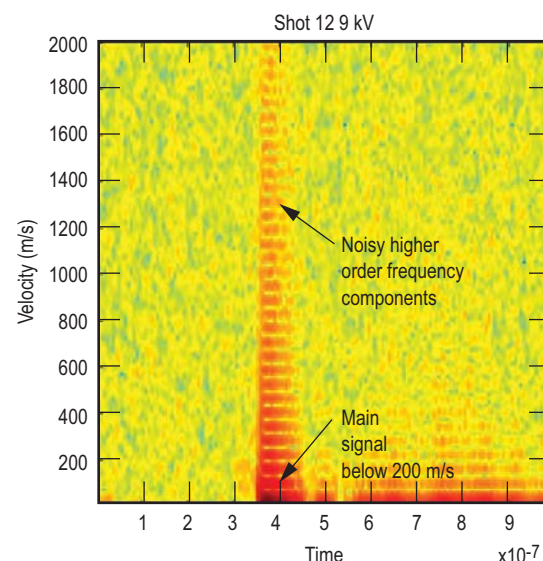


Figure 4. Sample PDV results, showing noisy return signal and low expansion speed.

signal-to-noise is not strong and the error bars in the expansion speed are fairly large.

Furthermore, even at the high end of $v \sim 1000$ m/s, an order-of-magnitude estimate of the pressure yields $P \sim \rho v^2 \sim 12$ atm for a mass corresponding to molecular nitrogen and ambient density. This is several orders of magnitude below typical shock initiation thresholds. Tests were done for 20-, 40-, and 150-mil arc lengths with source voltages in the 8 to 10 kV range, a 1-nF source capacitance, and a circuit inductance of about 250 nH. If the peak pressure in the arc volume resulted from all of the energy initially stored in the fireset, it would be of the order 600 atm at the 40-mil spacing, assuming an initial arc diameter even as large as 1 mm.

Thus, these results again point to the importance of understanding the correct energy transport, since a considerable amount of energy is not accounted for.

Related References

1. Lee, E. L., and C. M. Tarver, "Phenomenological Model of Shock Initiation in Heterogeneous Explosives," *Physics of Fluids*, **12**, pp. 2362-72, 1980.
2. Strand, O. T., et al., "Compact System for High-Speed Velocimetry Using Heterodyne Techniques," *Review of Scientific Instruments*, **8**, pp. 83108-1-8, 2006.